PLAN AND CONSTRUCTION OF CABLE-STAYED BRIDGE SIDE SPAN BY LARGE BLOCK METHOD

Hiroshi KUDO
Structural Engineering Division, CHODAI Co.,LTD. Japan
kudou-h@chodai.co.jp

Nakamura HITOSHI
Structural Engineering Division, CHODAI Co.,LTD. Japan
Nakam-ht@chodai.co.jp

Hae-Il PARK
Deputy General Manager, Samsung C&T Corporation Co., Ltd.
Haeilss.park@samsung.com

Shae-Eun PARK
Assistant Manager, Samsung C&T Corporation Co., Ltd.
shaeeun.park@samsung.com

Dong-Wan KIM
General Manager, Samsung C&T Corporation Co., Ltd.
wallgye@samsung.com

Wan-Soo LEE
General Manager, Samsung C&T Corporation Co., Ltd.
wsboss@samsung.com

Abstract

Girder of Incheon Bridge side span was divided into four large blocks and was constructed using the 3000ton FC"Samsung". The west side 1st block was constructed on 2007.DEC.3 and the last block east 4th block was constructed on 2008.MAR.1. Adoption of large block construction method contributed to improve workability and drastic shortening of construction period on site. This paper reports study of construction method of side span girder, checking of structure and construction.
In the first of the paper, large block construction using temporary bent and balanced cantilever erection method which used diagonal prop is compared from a view of wind resistance and economical. In the second, detailed design of large block construction is described.

Study of Construction Method (1) Balanced Cantilever Method and Large Block Method

1. Study principle

Span length between pylon and supplemental pier is 280m. There are two methods as the construction method of this span. One is a balanced cantilever method using diagonal prop and the others is a large block construction using temporary bent. First of study, the possibility of balanced cantilever method using diagonal prop is examined in the determination of construction method and equipment.

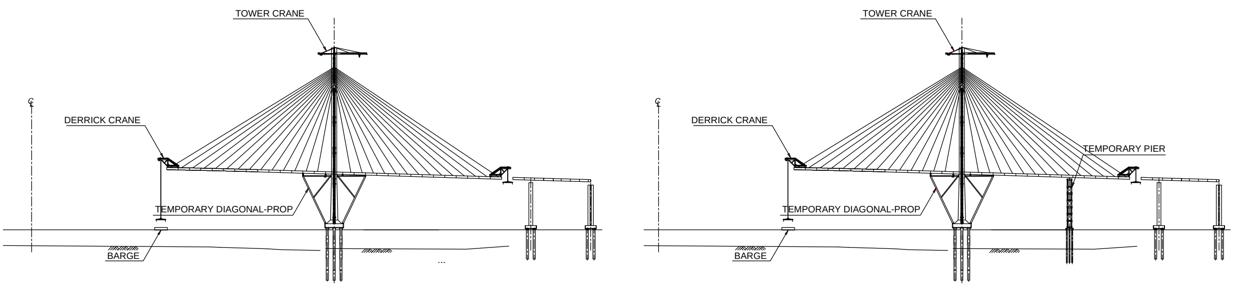
When balanced cantilever method is applied for Incheon Bridge, cantilever length would be 221m and the length would be a world longest class. This structure is assumed that vertical vibration due to turbulence of wind is large before side span close which structure

Table-1 Condition of gust analysis

	Complete	Construction
Design wind speed U10	35m/sec	25m/sec
Wind speed (h=81.583m)	54.20m/sec	38.72m/sec
Power spectrum	Karman Spectrum; ESDU85020	
Intensity of turbulence	Iu=0.114, Lu=548 Iw=0.063, Lw=46 Iv=Iu*0.75	
Aerodynamic admittance	Drag; Davenport Lift, moment; Sears	
Structural damping	0.02	

system is unstable. In order to evaluate the balanced cantilever method, gust analysis including lift and wind tunnel test during construction was executed and the safety of a structure is checked. Response o f turbulence of wind is estimated by the numerical computation which used the statistics technique. The characteristic of wind is used based on observation result on the site and aerodynamic coefficient of girder section is used result of 2-dimensional wind tunnel test. Characteristics of wind are shown in Table-1. Examination item is as follows.

1) Sectional force of pylon



Diagonal prop　　　　　Diagonal prop + Temporary bent

Figure 1 Temporary support type

2) Check of workability on girder
3) Design of diagonal prop

2. Study of construction method based on gust response analysis

1) Before side span closure

Type of temporary support is considered the case of only diagonal prop shown in Figure 1 a nd the case of diagonal prop and temporary bent. Pylon section in longitudinal direction and diagonal prop before side span closure are decided by lift gust response of transverse direction wind. Dynamic vertical displacement at the end of center span in the case of only diagonal prop is 868mm. If primary vertical mode (f= 0.1155Hz) is dominant in the vertical vibration, acceleration is estimated as 46gal. Acceptable acceleration is 50gal (more than 20m/s of wind velocity) shown in design specifi cation CSR. This result show that displacement is large but it is below the allowable value. On the other hand, when temporary bent is added, the dynamic vertical displacement is sharply reduced to 210mm.

In addition, in the case only by temporary bent which removed diagonal prop, dynamic vertical displacement is 228mm. It is equivalent to the case of temporary bent + diagonal prop and it is thought that temporary bent is effective to improve workability.

Bending moment of pylon in plane by gust analysis before side span closure and before center span closure is shown in Table 2. In the case of only diagonal prop, bending moment of pylon has exceeded sectional force at completion and it is necessary to check stress of pylon and diagonal prop at unbalanced dead load state during construction. Result of design calculation, even if it multiplied the result of gust analysis by 1.7 as a safety factor in consideration of actual phenomenon, it is confirmed the pylon section will not be changed.

Table-2 Result of gust analysis

	Bending moment of pylon	Vertical deflection at
Completion	234401 kNm	0.745 m
Before side span closure (Diagonal prop)	***394272 kNm***	***0.868 m***
Before side span closure (Diagonal prop + pier)	163799 kNm	0.210 m
Before center span closure (without temp. pier)	117516 kNm	0.415 m

2) before center span closure

In the case without all temporary piers, displacement of girder end is 415mm. All gust response in the

case without temporary bent is less than sectional force at completion. It is thought that existence of temporary bent does not affect wind stability.

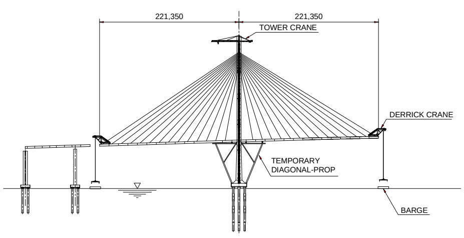
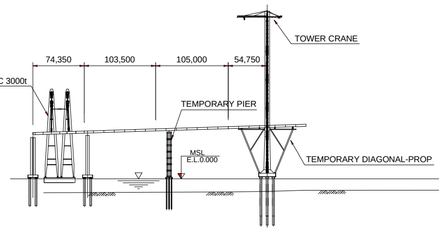
3) Conclusion

In the whole bridges wind tunnel test, larger response than a gust response analysis value is often obtained as vertical vibration of girder. It is considered to be the cause that variation of power spectrum may be large compared with the power spectrum estimated in a gust analysis which assumed the power spectrum smoothly and the influence of scale of turbulence appears greatly especially in the stage where balance cantilever length is short.
The above mentioned point is also considering, the large block construction method with temporary bent is selected from the following reasons.

- Site construction period can be shortened by large block construction
- Workability may worse in actual condition

Comparison result is summarized in Table 3.

Table-3 Comparison of construction method

	Balanced cantilever erection with diagonal prop	Large block erection method with temporary pier
Construction method		
Concept	After large block construction around pylon, 11-block balaned cantilever erection is started. Maximum length of cantilever is 221.35m and the length is the world longest class.	Side span is constructed as 4-large block construction. Construction procedure of large block is restrictions according to the manufacture process of girder and the construction process of ship protection.
Wind resistance	Maximum cantilever length during construction is long and possibility that wind resistance stability during balanced cantilever erection will be a problem is high. Wind tunnel test is indispensable. Design load of diagonal prop is determined by Vertical deflection due to gust, 868mm Vertical accelelation 46gal (f=0.1155Hz)	Since the side span is supported by temporary bent, the structure system is stable. The span length at construction exceeds 100m and the rigidity of girder before cable construction is small. Notice to vortex excitation is required. Vertical deflection due to gust, 210mm
Diagonal prop	Support reaction of diagonal prop 14900kN (Strength Limit State)	Support reaction; Construction from pylon to end, 17400kN Close at 3rd span from end, 14500kN (Strength)
Pylon and girder	Cross-sectional force of pylon by gust during construction is large, but there is not necessary to change the section.	Reinforcement above temporary shoe and in order to narrow a diaphragm interval to raise a compression strength of lower flange, it is necessary to add a diaphragm near temporary bent.
Economical	Increase of thichness of girder is unnecessary to the section determined by the completion system. Moreover, since design sectional force of diagonal prop is also small, steel weight is smaller than large block construction method. However, mesure for wind stability, such as TMD and stay resisting to wind,	A temporary bent is added. Reinforcement quantity of girder changes by construction procedure. Reinforcement of girder is increases maximum about 20%.
Construction period	construction period is longer than large block construction method.	Construction period at site can be reduced very much. Since the period of 1cycle of cantilever construction of center span can be reduce one to two days, total construction period can be shortened.
Evaluation	Economical efficiency is good. However, wind resistance stability during balance cantilever erection is bad, and disadvantageous in workability and construction period. △	Cantilever construction is only center span and its wind resistance stability improves. Workability is good. Construction period can be shortened. Although it is thought that economical efficiency is inferior since reinforcement of girder and diagonal prop is needed, it can be improved by construction procedure. O

Study of Construction Method (2) Study of Temporary Bent Position and Block Length

1. Study of temporary bent position

From the examination result of temporary bent positions, large block construction method which prepared two temporary bent is recommended from wind resistance and construction period.

2. Study of Block length

1) Block length of block next to pylon (1st block BB-4)

Block divided position is determined by following conditions.

- The maximum component length is set to L<120m from 80% of capability of 3000tFC.
- Block length (weight) is made equal as much as possible.

- The 1st block is set to block length including the lowest cable position of center span in order to reduce construction period of center span.

From the above conditions, the 1st block is projected 26.35m to center span from pylon. Moreover, when the length to the side of side span is short, it is assumed that a center-of-gravity position is close to a pylon and cannot secure the space between FC and pylon at the time of suspension. The 1st block length is 112.7m as shown in Table-4.

2) Span arrangement of temporary bent

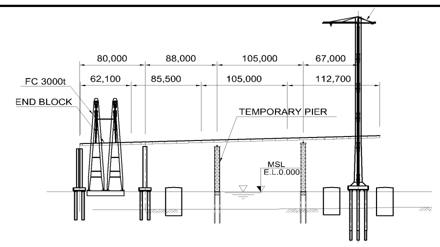
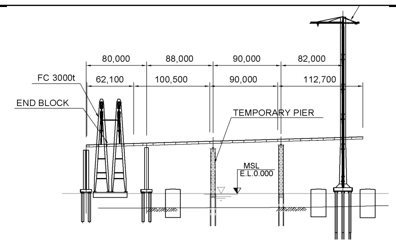
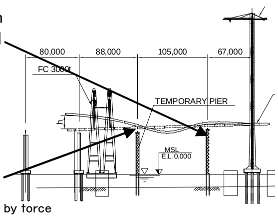
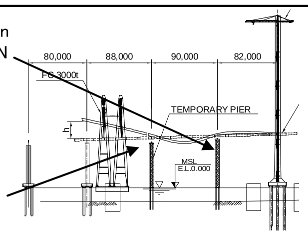
The installation position of temporary bent and block length are considered the following two ideas.

(1) 1 block extended out of bent position. - Joint angle adjustment is easy.

(2) Block end is near by temporary bent. - Moment after all large block set is small.

Reinforcement steel weight and joint angle is calculated about the above two ideas. As a result of comparison as shown in Table 4, the position of 1-block extended out of bent position which compelling force at the time of connection is small and excellent in workability and this proposal is selected.

Table 4 Study of temporary bent position and block length

	The position which give priority to Joint angle adjustment	The position considering moment balance
Block length Span length		
Concept	The proposal which extend 1 block out of bent position in order to make joint angle adjustment easy. It is advantage that the plate thickness of joint part is small.	This proposal is planned to be about equal span length considering the moment after all large block construction. It has advantageous that scaffold is close to bent position.
Bent reaction and Joint angle	Bent reaction R=22,828 kN  Joint angle Rt1=9.383 * When joint angle is adjusted by force Introduced moment at connection* M1=P1xL1 (Cantilever length from bent L1=19.35m) M1=Rt1/Rt2*M2=1.25M2, ***P1=0.28P2***	Bent reaction R=20,716 kN  Joint angle Rt2=7.468 Introduced moment at connection* M2=P2xL2 (Cantilever length from bent L2=4.35m)
Reinforcement	Steel weight 170ton/Br.	Steel weight 160ton/Br.
Evaluation	As a result of rough calculation, compared with the 2nd proposal, compelling force at the time of joint angle adjustment becomes about 30%, and it is advantageous for construction. Moreover, since lower flange thickness of the joint part is thin as 12mm to 19mm of the 2nd proposal and the connection structure is small. This proposal is recommended. O	Reinforcement steel weight can be reduced a little, the angle of joint part is small and the position of scaffolding is advantageous as compared with the 1st proposal. However, since compelling force at the time of joint angle adjustment is large, structure for erection, such as strongback, increases and construction is inferior to the 1st proposal. △

Detail Design of Girder by Large Block Method

1. Joint angle adjustment of large block girder

1) Design principle

Although the connection position of a large block selected a comparatively small position of bending moment, it is not avoided that a certain bending moment of the connection part arises at the time of closure.

Angle of joint of large blocks should be coincided or should be introduced compelling force. In Incheon Bridge, the following three methods of connecting can be considered.

Method 1; Connecting under suspending by FC

It is a method of doing connection work under suspending by FC and the whole block is inclined by

jack or FC so that a angle of joint between block suspended by FC and joint of an existing girder.

Method 2; Connecting after loading to bent +Jack up

First, weight of suspended girder is put on a existing girder by setting beam. And after installing the opposite side of girder to a shoe on pier (or temporary bent), FC leaves. Next, the angle of both of joint makes coincide by jack up at required support and doing connection work.

The amount of required jack up in each support for joint angle adjustment is shown in Figure 2.

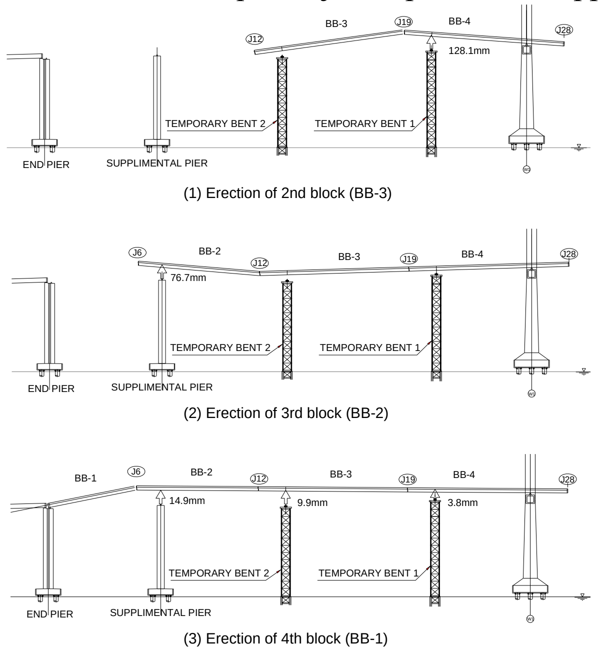


Figure 2 Jack up of method connecting after release from FC

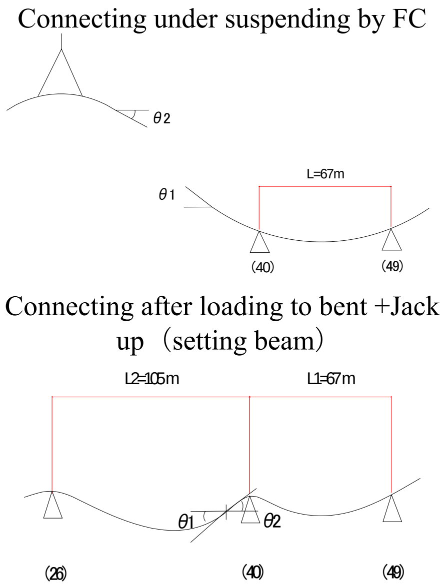


Figure 3 Joint angle

Method 3; Connecting after loading to bent + compelling moment

First, weight of suspended girder is put on a existing girder by setting beam. And after installing the opposite side of girder to a shoe on pier (or temporary bent), FC leaves. Next, a joint angle is coincided adding compelling bending moment using tension jack and fixing equipment installed on deck or lower flange.

As a result of construction analysis, when a 200ton jack is applied, for closure at the 2nd, 3rd and 4th block construction, the number of jack is required 5 and 2 or 1 set.

2) Comparison of method 1 and 2

In two construction methods Method 1 and 2, the amount of jack up to coincide joint angle is calculated. θ1 is a rotation angle of joint of large block to construct, and θ2 is a rotation angle of a existing block. The analysis result by each construction method is shown in Table-5. According to this result, jack up of Method 2 is much smaller than Method1 connecting under suspending by FC. Considering construction, Method 2 is more advantageous. As an example, modification of girder when constructing the 3rd block and distribution of bending

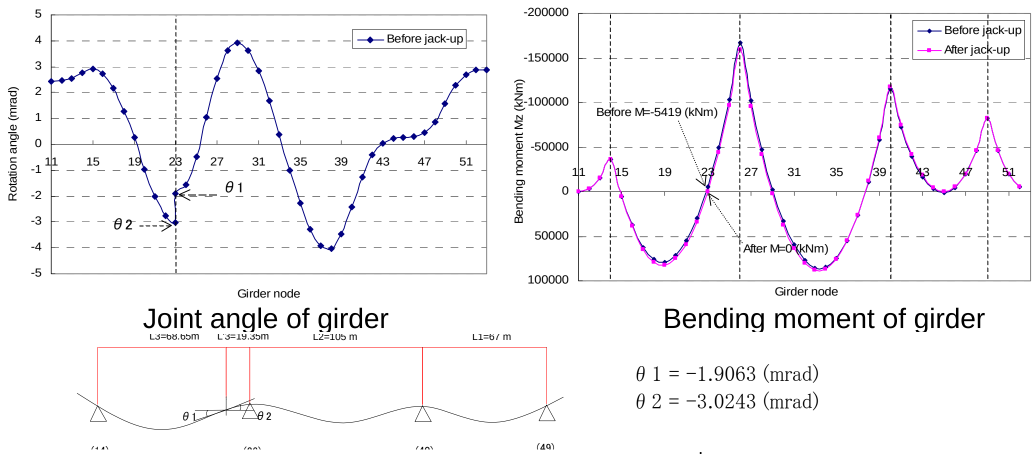


Figure 4 Joint angle and bending moment at 3rd block (BB-2) erection

moment before and after jack up by Method 2 are shown in Figure 4. Since it is |θ1|<|θ2|, if jack up at left end supplemental pier, the moment of a joint is made to 0.

Table 5 Joint angles and jack up by each method

	Connect while suspending by FC				Connect after release from FC			
Step	θ 1(mrad)	θ 2(mrad)	Jack-up(mm	Jack point	θ 1(mrad)	θ 2(mrad)	Jack-up(mm	Jack point
2nd Block	1.457	3.493	136.4	Bent 1	−8.556	−4.718	128.1	Bent 1
3rd Block	8.432	2.14	1082.2	Pylon	−1.906	−3.024		
			660.6	Bent 1			76.7	Bent 1
4th Block	−1.993	0.066	535.3	Mid pier	−2.825	−2.511	14.9	Mid pier
			354.1	Bent 2			9.9	Bent 2
			137.9	Bent 1			3.8	Bent 1

3) Conclusion

There is about 9m change of tide at Incheon Bridge and holding a large block into the same height and angle for a long time requires advanced navigation skill. Method 2 using setting beam is suitable.

2. Stress check during large block construction

Stress checking of girder of large block construction is examined to each construction step. Sectional force during construction and sectional force of live load are shown in Figure-5. Section is checked according to AASHTO LRFD same as a completion system. Load factor of dead load takes 1.25DC into consideration to Strength Limit State. The lower flange compression stress at the time of FC lifting of BB-4 is 205MPa and it is enough smaller than strength limit 284MPa of stiffened plate based on FHWA-TS-80-205.

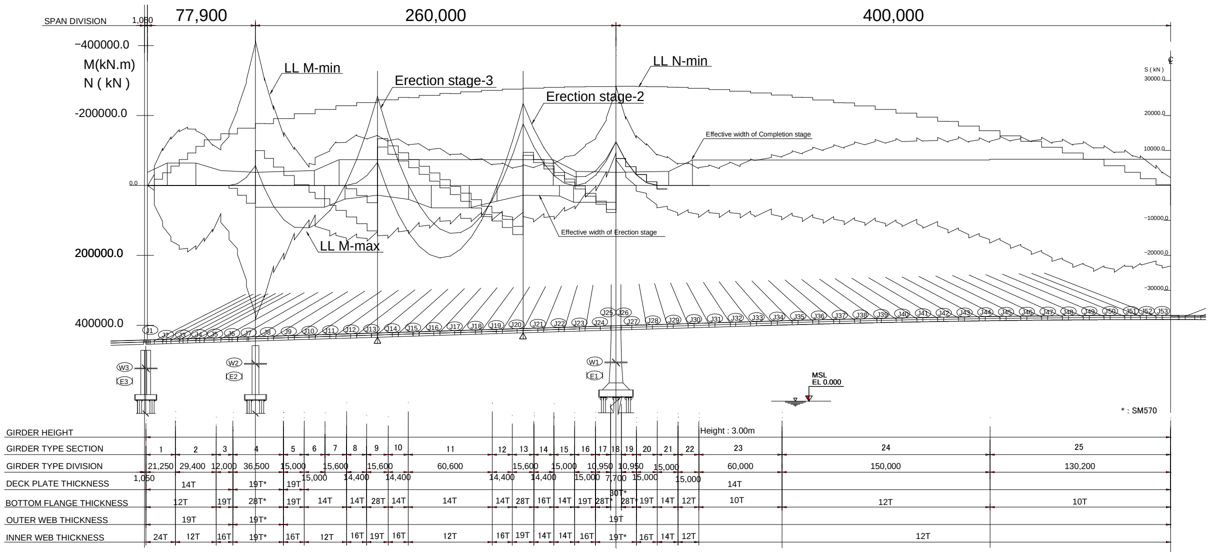


Figure 5 Sectional forces during construction

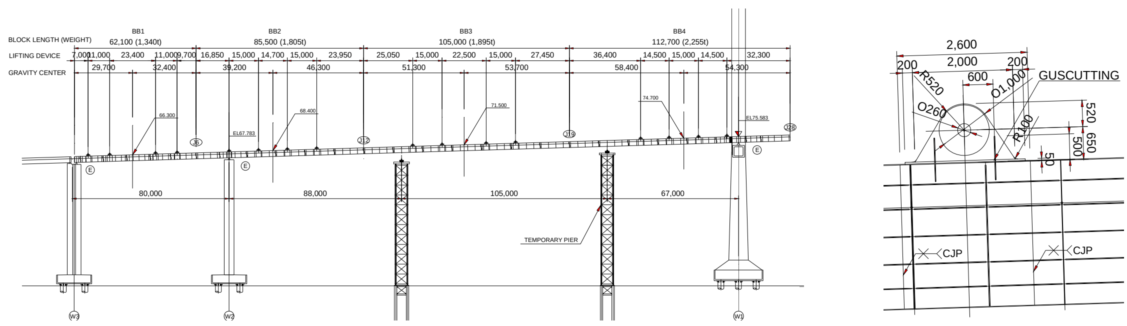


Figure 6 Lifting device position and lifting device

3. Design of erection equipment

1) lifting device

Lifting device position for FC and lifting device are shown in Figure 6.

2) setting beam

In construction of a large block, setting beam is used in order to release FC at an early time. The structure of setting beam is shown in Figure 7.

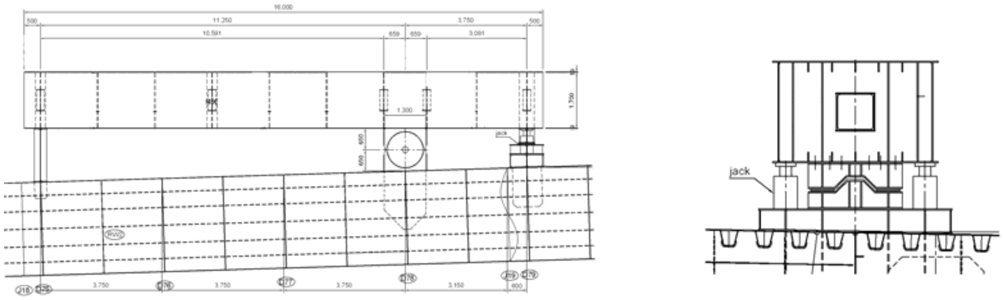


Figure 7 Setting beam

Support condition of girder during large block erection

1. Adjustment of bearing position at large block construction

Just after large block erection, axial force is not introduced into girder, and a girder shrink by temperature change. Therefore, it is necessary to adjust a bearing position during construction. The adjustment plan of shoe is described in below at the time of (1) large block construction (2) set back at center span closure.

1) 1st block (BB-4) erection

(a) Install a large block on rubber bearing of pylon, and carry out temporary fixation with rubber bearing and girder by bolt. This temporary fixation shall be released at the time of center span closure.
(b) Move bent 1 into longitudinal direction by winch, and fixes a shoe of bent to the base plate of girder.
(c) In order that 1st large block go through a pylon 26.35m in longitudinal direction, there is a possibility that faring contact with pylon. Faring by the side of center span was removed and prepared a guide for contact prevention (Picture-1).

2) 2nd block (BB-3) erection

(a) Prepare setting beam (Figure 7) on BB-4 side end of BB-3 so that the load of BB-3 is put on BB-4.
(b) BB-3 put on BB-4 by setting beam. Move bent 1 into longitudinal direction by winch, and fixes a shoe of bent 1 to the base plate of BB-3.
(c) Jack up BB-4 128mm at bent 1 in order to coincide the joint angle between BB-4 and BB-3 and jack down after connection of both blocks. Jack on temporary bent is shown in Picture-2.

3) 3rd and 4th block(BB-2,1) erection

(a) BB-2 or 1 put on a existing girder by setting beam. Girder is loaded on rubber bearing on supplemental and end pier. The position of rubber bearing is adjusted and fixed by bolt to the girder.
(b) In order to coincide joint angle of both girder, jack up the required quantity at supplemental pier and bent position. Jack down after connection.

2. Setting position of rubber bearing

Rubber bearing is fixed to the final position of girder in the standard temperature (15deg) at completion. The final position is determines and corrects considering the amount of shrinkage by increase axial force from large block installation to completion, manufacture construction error and the amount of elasticity by a temperature change. The amount of shrinkage of girder by increasing

axial force from large block installation to completion is shown in Figure-8.

For horizontal adjustment of rubber bearing, the lower part of rubber bearing is pushed to a neutral position by jack installed in steel frame on the pier top. Rubber bearing of supplemental and end pier is fixed to base plate temporary with bolt during cable construction, and after closure of center span, lower shoes and base plate is weld after checking that shoes are installed in a planed position.

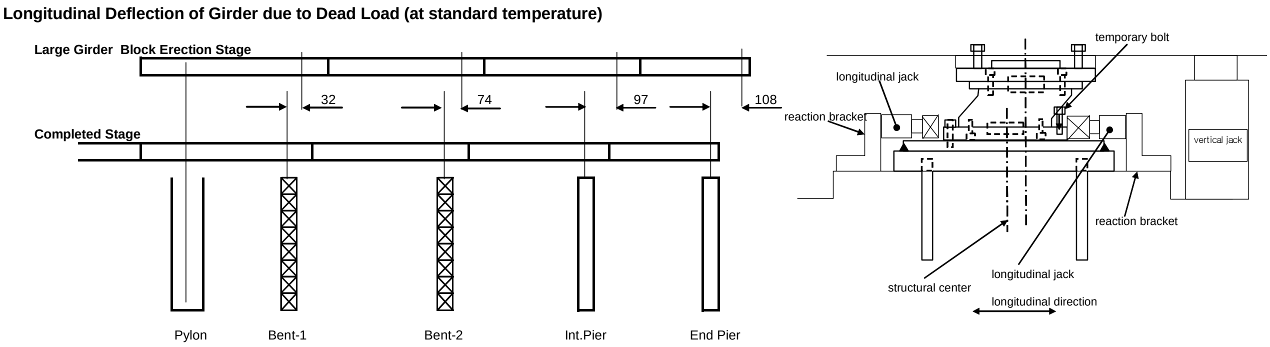


Figure 8 Adjustment of rubber bearing position

3. Adjustment of bearing position at set back of center span closure

When the center span closure segment is lifted, existing girder should be set back. Girder is forced and shifted by jack and center hall jack which are installed on pylon, supplemental pier and end pier. When the shear spring of all rubber bearing is effective, the jack introduction force for set back is very large. Therefore, at the time of set back, set bolt of rubber bearing of pylon is released so that the shear spring which does not work. After closure, the rubber bearing is fixed in a neutral position.

CONCLUSION

This paper reports the study and detail design of large block construction of Incheon bridge side span. Girder of cable stayed bridge was closed safely on December 16, 2008. In the design of Incheon Bridge, design and construction is progressed simultaneously with a Fast truck system. We were in charge of the design having a feeling of tension. The plan of large block construction also designed in cooperation with the wind tunnel test, design adviser and construction group. We'd like to express appreciate to all relevant people.

Picture 1 Erection of BB-4

Picture 2 Large block

Picture 3 Jack on temporary bent

Picture 4 Adjustment at shoe of pylon

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